INTERSTELLAR COSMIC RAY AND PLANETARY MAGNETOSPHERES EXPERIMENT

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August 1972

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TECHNICAL SECTION

2. ABSTRACT

We propose to measure the spectrum of electrons from 3 - 110 MeV and the spectrum and elemental composition of all cosmic-ray nuclei from hydrogen through iron over an energy range from ~ 1 - 500 MeV/nuc. Isotope studies will be made from hydrogen through sulfur from ~ 1 - 75 MeV/nuc. These studies will provide information on the energy content, origin and acceleration process, life history, and dynamical contribution of cosmic rays in the galaxy as well as an understanding of the nucleo-synthesis of elements in the cosmic-ray sources. Particular emphasis will be placed on low-energy phenomena that are expected to exist in interstellar space, but cannot be observed from the inner solar system. In a similar way elemental and isotopic studies will provide definitive information on the origin of the Jovian trapped radiation as well as the nature of the diffusion and atmospheric loss processes. Our instrument package should give data over the complete Jovian encounter trajectory as well as offering high sensitivity for exploring the magnetosphere of Saturn. Finally, these studies will provide an understanding of the transport of cosmic rays over an extended region of interplanetary space and a determination of the location of the modulation boundary. A major contribution to all these areas is the fact that we can measure streaming patterns of nuclei from H through Fe and electrons over an extended energy range, with a precision that will allow determination of anisotropies down to 0.1%.

The characteristics of the three detector systems we have developed to make these measurements are outlined on the following summary page. The required combination of charge resolution, reliability and redundance can best be achieved with systems consisting entirely of solid-state charged-particle detectors. New developments in solid-state detector technology such as anticoincidence guard rings and curved detectors allow one to achieve charge and energy resolution previously unattainable even on Earth satellites. Finally, we have designed, tested and calibrated a new, very light cosmic-ray electron detector system for the crucial 3 - 110 MeV region.

3. EXPERIMENT SUMMARY CHART

INTERSTELLAR COSMIC-RAY AND PLANETARY MAGNETOSPHERES EXPERIMENT

This experiment consists of three basic detector systems, a High-Energy Telescope System (HETS), a Low-Energy Telescope System (LETS), and the Electron Telescope (TET). Each telescope system consists of an array of solid-state detectors, and multi-parameter analysis is performed over the complete charge and energy range (except the lowest portion of the H and He spectra).

Charge, Isotope, and Energy Range

Nuclei	$(Z = 1,2)$	0.15 - 1 MeV/nuc	(Single parameter analysis)
	$(1 \leq Z \leq 30)$	$\sim$ 1 - 500 MeV/nuc	(Multi-parameter analysis)
Electrons		$\sim$ 3 - 110 MeV	
Isotopes	$(Z = 1,2)$	$\sim$ 1 - 75 MeV/nuc	$(\Delta M = 1)$
	$(3 \leq Z \leq 8)$	$\sim$ 2 - 120 MeV/nuc	$(\Delta M = 1)$
	$(9 \leq Z \leq 16)$	$\sim$ 2 - 120 MeV/nuc	$(\Delta M = 2)$

Anisotropies

Nuclei	0.15 - 150 MeV/nuc	(4 directions)
	$\gtrsim$ 150 MeV/nuc	(2 directions)
Electrons	3 - 10 MeV	(3 directions)

Flux Dynamic Range

Nuclei ($\sim$ 1 - 8 MeV/nuc) 10^{-6} to $> 10^{4}$ cm^{-2} sec^{-1}
($> 10^{8}$ can be attained with a simple modification)

Electrons (3 - 10 MeV) 10^{-3} to $> 10^{4}$ cm^{-2} sec^{-1}

Geometrical Factors

LETS	12 cm^2-sr (single parameter)
	2 cm^2-sr (multi-parameter)
HETS	4 - 8 cm^2-sr (energy dependent)
TET	0.6 - 1.8 cm^2-sr (energy dependent)

Weight 4.45 kg (9.8 lb), including stepping platform for anisotropy measurements

Power 4.8 W

Volume 30 cm x 30 cm x 20 cm high electronics box with detector assemblies extending a maximum of 15 cm additional.

Thermal -40°C to +35°C maximum, -20°C to +15°C preferred.

Calibration Self-calibrating in flight. HET/LET and HET/TET energy ranges overlap.

Allowable Material in Field of View

0 mg/cm^2 for HET (S_1), 50 mg/cm^2 for HET (S_2 + P)
0 for LET
<100 mg/cm^2 for TET

4. Scientific Objectives

(I) One basic goal of this experiment will be to measure the spectrum of electrons and the spectrum and elemental and isotopic composition of all cosmic-ray nuclei from hydrogen to iron and beyond. Multi-parameter analysis of these charge and mass components and their streaming patterns will be made at energies down to ~ 1 MeV. The object of these studies will be to understand the nucleosynthesis of elements in the cosmic-ray sources and the origin and acceleration process, life history, and dynamic contribution of cosmic rays in the galaxy. Particular emphasis will be placed on low-energy phenomena that are expected to exist in interstellar space but cannot be observed from the inner solar system.

(II) A second objective will be to study the (trapped) planetary energetic-particle environment in the Jovian radiation belt and in the almost totally unknown environment of Saturn, with the specific objective of determining the origin of these belts.

(III) A third goal will be to make comprehensive measurements of the intensity and directional characteristics of the energetic-particle population (solar and galactic cosmic-ray nuclei and electrons) as a function of radial distance from the sun. The object of these studies is to understand the transport (modulation) of cosmic rays over an extended region of interplanetary space, and to determine the location of the modulation boundary.

4a. Experiment Rationale

Numerous cosmic-ray experiments have been made on space probes near the earth, and extending out to perhaps several AU from the sun in the case of the Pioneer 10 and G missions. It is fair to ask what can the present experiment achieve beyond the past achievements or those expected from Pioneers 10 and G.

Basically, this experiment package builds upon the highly successful new telescope employed by the GSFC-UNH group on the Pioneer 10 and G spacecraft - a telescope that employed for the first time the technique of multi-parameter analysis and consistency criteria to determine cosmic-ray charge spectra. The proposed high-energy telescope uses curved dE/dx telescope elements in a unique double-ended "thick-thin" arrangement. The use of curved elements not only greatly reduces the effects of path length differences but also allows significantly larger geometrical factors to be employed. The charge and mass resolution of previous cosmic-ray telescopes used in space including those on Pioneer 10 and G has been limited by the path-length effect; now it will be possible to achieve charge resolution up to a $Z \approx 30$, and isotope resolution up to $Z \sim 8$ (for $\Delta M = 2$, isotope resolution up to a $Z \approx 16$). The use of multi-parameter analysis plus consistency criteria along with a guard counter arrangement will effectively eliminate background as a problem affecting resolution. This assures that the ultimate solid-state detector resolution will be obtained for the first time.

We will have a geometrical factor ~ 8 cm^2-sr for nuclei. This is a factor ~ 4 times larger than typical earth satellite systems used in the past (~ 40 times larger than the telescopes now on Pioneer 10 and G). This large geometrical factor is of vital importance in many areas; for example, we expect to observe $\sim 10{,}000$ Be or Fe nuclei in one year. Isotopes such as ^{10}Be and less abundant nuclei such as K and Ni have abundances ~ 0.1 Fe and will be easily studied in the proposed experiment, whereas this has not been possible on <u>any</u> of the previous IMP, OGO or Pioneer systems.

We also expect to observe anisotropies of $\sim 0.1\%$ over reasonable energy intervals in one year. Such sensitivity is completely out of the range of the present Pioneer 10 and G telescopes or of telescopes that would utilize the planned roll periods of the MJS spacecraft.

The proposed experiment will place particular emphasis on the low-energy galactic nuclei that can be observed outside of the solar cavity. Multi-parameter analysis will be extended down to $\sim$ 1 MeV/nuc for protons and heavier nuclei up to iron. At the same time the instrument will provide accurate spectra up to $\sim$ 500 MeV/nuc and above, for a direct comparison with the comprehensive data available near the earth.

The instrument package will include a lightweight electron detector to cover the range from $\sim$ 3 MeV to $\gtrsim$ 110 MeV, to study this component in an energy range where nothing at all is known about the galactic spectrum. Here the solar modulation and interplanetary radial gradient effects are very uncertain and are fundamental to our understanding of the transport of low-rigidity particles in the interplanetary medium.

We believe that in a snapshot-type exploratory fly-by mission, the instrumentation philosophy for the exploration of planetary magnetospheres should not be the same as for an orbiter. The elemental and isotopic resolution and the sensitivity and directional characteristics of the cosmic-ray telescopes of this experiment will serve excellently for the whole encounter with the nominal-model Jovian magnetosphere and over the full range of weaker magnetospheres as might be the case for Saturn. If Pioneers 10 and G should encounter flux levels significantly higher than those predicted by the nominal model, we are prepared to accommodate these higher flux levels with a simple modification to one of our low-energy telescopes.

5. Specific Results to be Expected

An extensive and comprehensive discussion of the scientific objectives of the MJS missions has been presented in the report of the Energetic-Particles Team of the mission definition phase. We shall consider here some of the more important specific results to be expected from this experiment.

I. Galactic Phenomena

Since the MJS missions are designed to reach at least 10 AU (even if one ignores the extended-mission phase), one can confidently expect to make the first *in situ* studies of scientifically-significant galactic phenomena. At present the observational evidence bearing on the question of reaching interstellar space (see Sec. 5 IIIB) indicates that the effective cosmic-ray modulation boundary lies within 10 AU.

A. Measurements of Cosmic-Ray Nuclei

A measurement of the spectrum and total intensity of galactic cosmic-ray protons and heavier nuclei down to energies $\lesssim$ 1 MeV/nuc is of fundamental importance. Low-energy galactic particles do not reach the earth because of interplanetary energy loss. All nuclei of energies less than a few hundred MeV/nuc observed at earth are believed to originate as nuclei of considerably higher energy in the galaxy because of this energy loss. Therefore, this measurement will provide the first determination of the total interstellar cosmic-ray energy density which is a basic quantity of importance in galactic dynamics and in the understanding of the evolution and stability of the galactic disk structure.

The proposed detailed measurements of the spectrum and abundance of the individual cosmic-ray nuclei allow the study of two particularly important problems. One is a determination of the injection spectrum and source abundance of the nuclei,

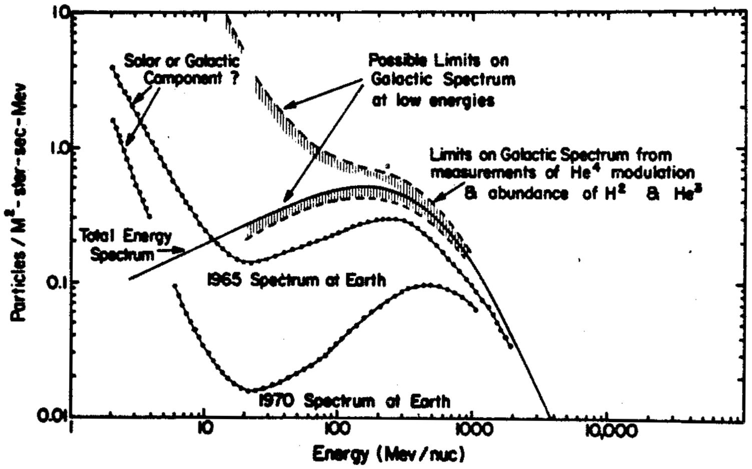


Fig. 5-1. Helium spectra observed at earth and limits on possible spectra in interstellar space.

the other is an understanding of the propagation of the cosmic ray nuclei in the galaxy. These two problems are closely intertwined in the cosmic-ray data and we shall now give some examples of specific measurements and what they can tell us about these problems and how they relate to some of the larger questions of galactic astrophysics.

(1) Measurements relating to the spectra and abundance of certain generically-related primary and "secondary" groups of nuclei. One such group of nuclei is the so-called "quartet", ^{1}H, ^{2}H , ^{3}He , ^{4}He. The secondary nuclei ^{2}H and ^{3}He are produced almost entirely from ^{4}He, and their production cross sections are well known. A careful study of the spectrum of these components can therefore provide information on the injection spectrum of ^{4}He and on the propagation and lifetime of ^{4}He nuclei in the galaxy. Already it is clear from the work of J. P. Meyer that the ^{4}He spectrum must closely resemble a total-energy spectrum at energies $\gtrsim$ 300 MeV. Below that energy, because of adiabatic energy loss in interplanetary space, the interstellar spectrum is unknown. Some possibilities for the low-energy He spectrum are indicated in Figure 5-1. A major goal of our experiment will be to measure this ^{4}He spectrum and the related ones for ^{2}H and ^{3}He. Because of the relatively long interaction-M.F.P. of the secondary ^{2}H and ^{3}He nuclei ($>$ 10 g/cm^{2}) in interstellar hydrogen one may utilize these data to examine spatial structure on the scale of the entire galaxy, e.g., these measurements will be valuable for understanding the rate of escape of cosmic rays to intergalactic space and related problems. To examine the propagation on a finer spatial scale it is necessary to study the spectrum, intensity, and isotopic composition of Li, Be, and B nuclei, which are primarily products of C and O interactions in the galaxy with an interaction M.F.P. $\sim$ 5 g/cm^{2}. In addition, to form a complete picture of cosmic-ray motion in the galaxy and to compare the source injection spectra for different charges it is necessary to study the fragmentation products of Fe (Z = 17 - 25 nuclei), which provide information on the very short path length distribution of the parent nuclei ($<$ 2 g/cm^{2}).

mean free path

The detailed cosmic-ray injection spectra and source elemental abundances over the entire range from Z = 1 - 30 which are determined from these studies may be used to understand the acceleration and escape processes of cosmic rays at the sources, and to provide input to the theories of nucleosynthesis in the cosmic-ray sources. These data will be free of any effects due to solar modulation, and the addition of isotopic measurements will more rigidly define several of the parameters entering into the calculations of nucleosynthesis (e.g., a determination of the ^{13}C/^{12}C, ^{20}Ne/^{22}Ne, ^{28}Si/^{30}Si, ratios).

(2) Measurements of the low-energy part of the spectra of all nuclei. At low energies, because of the ionization-range requirements, we are sampling a very local distribution of galactic cosmic rays. For example, the range of a 1 MeV proton in the typical galactic magnetic fields is $\sim$ 200 pc with a lifetime of $\sim 10^{4}$ years. A comparison of chemical abundances at low and high energies will be crucial to the separation of features related to the cosmic-ray injection and to the subsequent particle propagation in the galaxy. Possible nearby sources, such as pulsars, may also be identified by this technique.

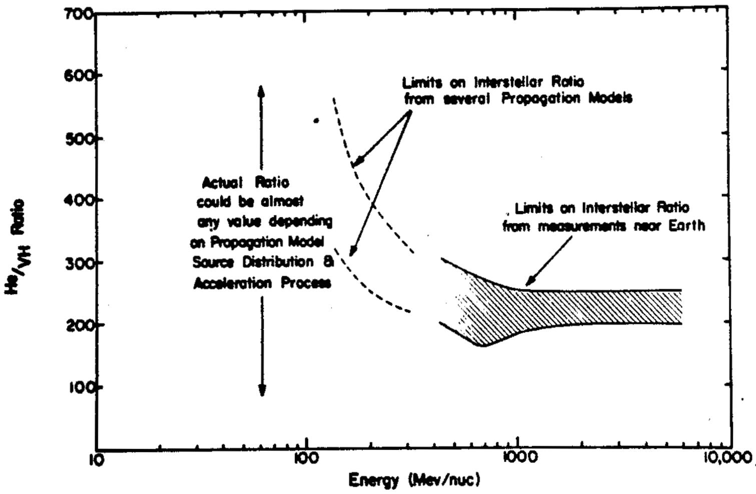


Fig. 5-2. Helium/VH ratio as a function of energy.

Compositional changes at low energies may indicate localized propagation effects, and even the existence of separate and localized cosmic-ray sources. Figure 5-2 shows some predictions of the various propagation models showing changes in the He/VH (VH means $20 \le Z \le 30$) ratio to be expected as a function of energy along with current limits on this very sensitive ratio at higher energies.

The specific details of the low-energy spectra - particularly for the heavier nuclei - are profoundly important from the point of view of the role of cosmic rays in the dynamics of the galaxy. To determine the role of cosmic rays in the heating of the interstellar medium by ionization loss, and in galactic x- or γ-ray production requires the study of the spectra of <u>all</u> the nuclei at the lowest energies; the heavier nuclei may play a very important role because of the Z^2 effect.

In all cases our multi-dimensional pulse height analysis energy limits will extend below the nuclear binding energy thresholds of $\sim$ 6 MeV/nuc. This will permit the study of any unusual abundances that might be related to nuclear reactions occurring in the cosmic-ray sources or in the interstellar medium.

(3) <u>Study of the particle flow patterns (anisotropies) of protons and helium nuclei</u>. We believe that a study of the anisotropies of galactic cosmic rays below 500 MeV/nuc and down to the lowest possible energies will be especially fruitful. In Tables 7-II and 7-III we indicate some of the anisotropy limits we expect to measure in the various energy ranges. Although the anisotropy observed near earth at very high energies ($\gtrsim$ 100 BeV) is certainly small, any attempt to estimate the anisotropy of the bulk of the cosmic rays (1 BeV and below) at present is sheer speculation. The magnitude of the anisotropy might vary widely with energy depending upon the distribution of cosmic-ray sources in the galaxy.

If the particles propagate locally in the galaxy by diffusing, one can directly relate the observed value of the anisotropy δ to the diffusion parameters by $\delta = \lambda/L$, where λ = diffusion M.F.P. and L is the length scale of the cosmic-ray density gradient. Because of rapid attenuation by ionization loss the anisotropies of low energy particles may be large. For example, since the range of a 1 MeV proton is $\sim$ 200 pc, a typical galactic diffusion M.F.P. $\sim$ 20 pc will give an anisotropy of $\sim$ 10% which is more than 10 times larger than our expected LET sensitivity at 1 MeV.

Even if local diffusion is not the principal mode of particle transport in the galaxy or if zero gradients arise because of the specific details of the geometry of our local region, similar general considerations still hold and anisotropy measurements at low energies can help to resolve these alternatives.

A basic point is that anisotropy and composition studies provide complementary information on the local cosmic-ray source distribution and local propagation parameters in the galaxy.

A study of the anisotropy of low-energy cosmic rays may be essential to determine the origin of the particles that are observed. Indeed this may be necessary to determine whether we are actually observing interstellar cosmic rays or not. For example, near the solar cavity there may be a large flux of low-energy particles flowing outward, particles that have lost energy near the sun by adiabatic cooling. The flux could mask a low-energy galactic component, and it will be necessary to have detailed anisotropy measurements to identify and separate them.

B. Measurements of Electrons

The measurement of the galactic intensity of electrons, specifically below ~ 100 MeV, will have a profound effect on our understanding of the role of these electrons in producing the diffuse x- and γ-ray background in the galactic disk, in understanding the dynamics of the galactic disk-halo magnetic-field relationship, as well as understanding the method of escape of these electrons from known source regions in the galaxy such as the Crab Nebula.

Above a few hundred MeV, the electron spectrum near the earth is reasonably well known, and, although less well understood, the broad features of the solar modulation have also been extensively measured and can be adequately determined at the orbit of earth. The understanding of the modulation at rigidities > 100 MV, to be gained from the study of nuclei on this mission, makes it possible to determine the galactic spectrum of electrons > 100 MeV outside of the solar cavity. Furthermore, using estimates of galactic radio emissivity obtained from measurements of non-thermal radio emission, under the assumption that this radio emission is caused by synchrotron radiation by energetic electrons in galactic magnetic fields, it is also possible to deduce the interstellar electron spectrum. A comparison of the galactic electron spectra obtained from these two approaches may be used to examine the spatial distributions of electrons and magnetic fields in the galaxy.

It should be noted that the radio measurements extend down to only ~ 1 MHz which corresponds to a few hundred MeV electron energy in the galactic magnetic fields. Below a few hundred MeV, we can only speculate on the interstellar electron spectrum. We believe therefore that it is most essential to make electron measurements at lower energies. For example, the low-energy galactic radio spectrum is observed to turn over and decrease below 1 MHz. It is usually assumed that this is due to free-free absorption by interstellar hydrogen. But is is possible that the electron spectrum itself turns over as well at the equivalent energies. Obviously the correct interpretation of this feature is of fundamental importance in understanding the conditions in the interstellar medium (e.g., the presence of cold gas clouds and the temperature of the intercloud medium) and for the understanding of the origin of these electrons and their importance in galactic dynamics.

If one extends the interstellar electron spectrum above 300 MeV, as deduced from radio background measurements, down to below 20 MeV, then it turns out that this spectrum exceeds that observed at earth by a factor of > 1000! Yet the spectrum observed at earth is roughly consistent with an interstellar knock-on origin for these electrons without invoking an additional, perhaps primary, source. Is this difference due to extremely large solar modulation effects or is the interstellar spectrum at low energies really not much different than at earth? Some of the rich possibilities for the behavior of the low-energy electron spectrum in interstellar space are illustrated in Figure 5-3. The resolution of this problem requires measurements of electrons specifically below 100 MeV.

II. Planetary Phenomena

The proposed studies of planetary trapped radiation provide an independent means of exploring the large-scale magnetic properties of Jupiter and Saturn and their environments. Measurements of many parameters of the trapped radiation will

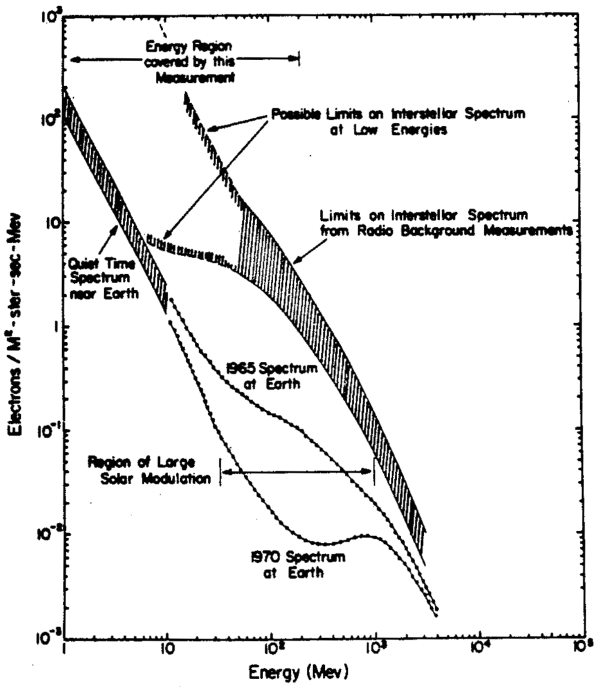


Fig. 5-3. Electron spectra observed at earth and limits on possible spectra in interstellar space.

give information on the interaction of the planets with the solar wind, on the origin of the energetic planetary particle population and its interaction with the atmospheres and satellites of the planets. Since the two giant planets represent significantly different physical systems, e.g., in the hypothetical strength of their respective magnetic fields, their distance from the Sun, and their satellite and ring environment) comparative studies will be particularly fruitful.

Our detector system has the versatility necessary to explore the widely differing conditions which might exist at the two planets.

MJS will probably represent the third traversal of the Jovian magnetosphere. We expect to have a reasonable estimate of the flux and energy spectra of the Jovian proton and electron components and their radial variations, which will be considered in our final MJS detector complement. As a significant step beyond the Pioneer 10 and G observations, we propose to determine the elemental and isotopic abundances and the angular distributions of the radiation belts. The proposed Low-Energy Telescope System (LETS) will measure nuclei over the full range of intensities expected for the MJS fly-by trajectories in the "nominal model" of the Jovian magnetosphere (Table 7-IV). Should Pioneer 10 indicate higher fluxes, a relatively simple modification will allow extension of its range to beyond the fluxes of the "upper-limit" model.

Just as elemental and isotopic studies provide information on the origin and interstellar travel of galactic cosmic rays, so should they provide information on the source of the radiation belts and the nature of the diffusion and atmospheric-loss processes. For example, at Earth one can postulate ionospheric, solar-wind, and/or neutron-albedo sources for the trapped radiation, and the composition should differ greatly among these different sources. The composition studies proposed here represent an extremely powerful tool, which only recently has been exploited at earth.

Saturn represents a quite different situation from Jupiter. We will be performing the first serious exploratory study of this planet. Recent radio observations suggest that Saturn may possess a weak magnetosphere. Our LETS will serve as an excellent system for exploring the low-energy-nuclei population of Saturn, including composition studies. In addition, as in the case of Jupiter, in regions of moderately-intense fluxes, the LETS will be complemented by the High-Energy Telescope System (HETS) and the Electron Telescope (TET).

Since one cannot comprehensively explore the radiation-belt dynamics on a single fly-by, we believe the composition studies will be the most meaningful and powerful exploratory tool one can use. In addition, our ability to measure electrons from 3 - 110 MeV will enable us to make comparative studies with local observations of the radio-astronomy team.

Further insight will be provided by our ability to carry out highly-detailed anisotropy and streaming measurements with our LETS. These data will give further information on magnetospheric diffusion processes, atmospheric loss processes, interactions with planetary ionospheres, and interaction with natural satellites and Saturn's rings.

III. Interplanetary Phenomena

A. Solar Modulation of Galactic Particles and the Radial Gradient

The solar wind modulates the intensity of galactic cosmic rays over a wide range of energies, with the effect being most severe at the lowest energies. Protons of several GeV energy are modulated only a few percent from solar maximum to solar minimum whereas the 10 MeV intensity is profoundly altered by modulation effects. Associated with this modulation must be a radial gradient of the cosmic-ray intensity, which is a measure of the local transport parameters (e.g., parallel diffusion coefficient). Our detector system is designed to measure the radial gradient and overall modulation as a function of rigidity over a wide range of energy and charge-to-mass ratio (e.g., ^{1}H, ^{4}He, electrons), in regions not yet penetrated by spacecraft. The new data will complement those of Pioneers 9 and 10 since this present spacecraft will go in a different direction relative to the solar apex, and be at a different time during the solar cycle, and will probably penetrate deeper. A determination of the rigidity dependence of this solar modulation will provide a measure of the effects of the radial diffusion coefficient integrated out to the modulation boundary.

The effectiveness of these studies will be enhanced by the presence of various isotopes (such as ^{1}H, ^{2}H, ^{3}He, ^{4}He) which can be used to distinguish between solar and galactic particles. Electron measurements will also be of great importance. In particular, measurements of the electron gradient and modulation over the energy range from 3 - 110 MeV, which we propose to do for the first time, will define the transport parameters over a rigidity range not readily accessible using low-energy proton measurements.

B. Modulation Boundary

At present, there is a strong indication that the scattering of cosmic rays essentially goes to zero at some distance $\lesssim$ 10 AU. Evidence for this comes from two directions. First, the decay of high-energy solar proton events is determined principally by leakage from the boundary, and this leads to a scale of 3 - 5 AU. Second, studies of the modulation of galactic particles suggest that the effective modulation boundary is within 10 AU. One of the primary goals of this experiment will be to determine the existence and location of this boundary. Basic aspects of the transport theory in interplanetary space depend on parameters at this boundary, and they are completely unknown.

In practice, it may be difficult to obtain a precise determination of the location of the boundary of the modulation region (where scattering effectively ceases) from a study of galactic particles alone. Studying the character of solar-flare particle events as a function of heliocentric radius should provide a very sensitive and precise indicator of the location of the boundary to the scattering region. In the inner solar system (observed at, say, energies of 10 - 50 MeV) a typical solar-flare event has a characteristic behavior in which the particles are highly anisotropic during the initial phase and then relax to a configuration in which the anisotropy is relatively small. This relaxation is due to scattering caused by magnetic irregularities. Beyond the boundary of the modulation region this scattering becomes small and observations of solar particles should reveal a highly-anisotropic flux of particles traveling outward along the large-scale magnetic field. Detailed analysis indicates that a typical solar-flare event should be readily observable beyond the boundary. This transition to highly-anisotropic solar particle events should provide an extremely sensitive signature of the presence of a boundary.

C. Anisotropies and Flow Patterns

The ability of our detector system to measure extremely low anisotropies ($\sim$ 0.1% in one year of operation) provides an opportunity to study the very important anisotropies which are a consequence of cosmic-ray transport in the solar wind. A measurement of the anisotropies provides a measure of the relative importance of perpendicular and parallel diffusion and convection, and can help define gradients out of the ecliptic plane. Anisotropy measurements effectively add another dimension to help complement intensity and composition measurements.

As one specific example of the kind of question we expect to be able to answer, consider the azimuthal anisotropy. Cosmic rays tend to corotate with the sun, and corotation by itself would produce an anisotropy of $\sim$ 20% in 1 MeV protons at 1 AU (this value scales as the inverse of the particle velocity and linearly with heliocentric radius). Departures from corotation occur as a consequence of diffusion normal to the spiral field and gradients out of the ecliptic. Measurement of the radial and energy dependence of the azimuthal anisotropy will help to determine the perpendicular diffusion coefficient and the normal gradient.

6. Experiment Design Philosophy and Approach

We propose the following measurements to meet the scientific objectives: charge and energy spectra; Z = 1 - 30, over an energy range of 0.15 - 500 MeV for H, to 2.5 - 500 MeV/nuc for Fe; Isotopes: Z = 1 - 8 ($\Delta M = 1$) and Z = 9 - 16 ($\Delta M = 2$) over a range $\sim$ 2 - 75 MeV/nuc; Electrons: 3 - 110 MeV. Anisotropies: all components ranging from H (0.15 - 150 MeV) to Fe (2.7 - 500 MeV/nuc) as well as 3 - 10 MeV electrons.

These measurements will be made with three detector systems; the High-Energy Telescope System (HETS), the Low-Energy Telescope System (LETS) and the Electron Telescope (TET). By using three independent systems, the charge and energy response and the background rejection can be optimized over a given energy interval while providing the redundancy that is vital for an extended mission. By using three-parameter analysis over almost the complete energy range, reducing the path-length variation through the use of curved dE/dx devices, and minimizing Landau effects by choosing the thickest dE/dx device appropriate to a given energy interval, we feel that for the first time in a space application, the ultimate solid-state-detector resolution will be realized. The double-ended approach in our High-Energy Telescope and the use of multiple (4) Low-Energy Telescopes provides the necessary geometric factor to do isotope and charge studies as well as measure low-level anisotropies.

The combination of charge resolution, reliability and redundancy can be realized only with telescope systems consisting entirely of solid-state charged-particle detectors. These devices have proven to be uniquely reliable in their space application. They are free of the gain changes associated with photomultipliers as well as being inherently more dependable. They also have sufficient low weight and bulk to allow the use of simple rotating devices for angular scanning. The three experimental groups have all flown stacked arrays of solid-state detectors similar to those proposed here. The HET and LET systems have evolved from the GSFC-UNH Pioneer 10 experiment and the CIT IMP H experiment. Similarly the TET is a special adaption of the HET and the CIT OGO VI experiment. In each case where a new item is used (e.g., large double-grooved detectors, the 20μ thick devices, the curved HET detector, or the telescope rotating mechanism) we have thoroughly tested this item in one of the three laboratories. In summary, we feel that these systems are in an advanced state of development and can be flown as we propose them.

In order to measure anisotropies to $\leq 0.1\%$ on the non-spinning MJS spacecraft we have developed a very light-weight stepping scan-platform which permits accurate intercalibration of our telescope arrays. The required accuracy is much greater than can be obtained using the anticipated roll periods of the MJS spacecraft. All detector systems operate in the self-calibrating dE/dx vs. E mode where particle-track end-points can be used to obtain an absolute calibration of the instruments. Therefore any drifts in gain and sensitivity can be accurately corrected for.

HIGH ENERGY TELESCOPE (HET)

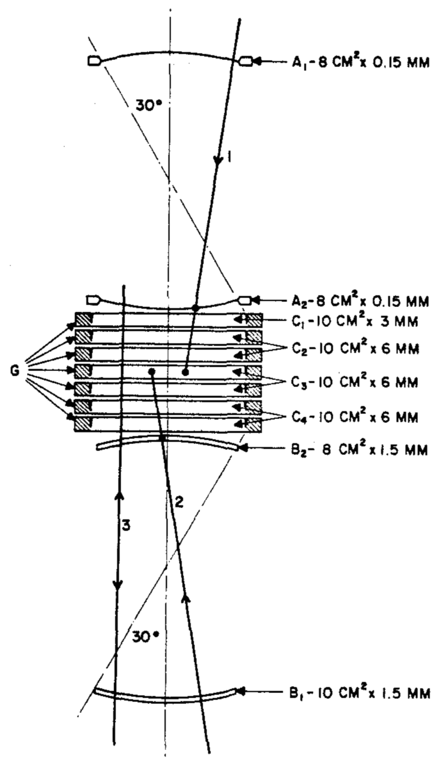


Fig. 7-1

7. Instrumentation

I. Detector Systems

A. The High-Energy Telescope System (HETS)

General Description. The MJS High-Energy Telescope System (HETS) consists of two identical telescopes, one fixed along the major axis of the spacecraft and the other scanning in the ecliptic. A schematic drawing of one of these is shown in Figure 7-1. The telescope is entirely solid state and makes use largely of detector technology already proven on Pioneer 10. However, new developments in solid-state detector technology and moderate increases in weight and power over Pioneer 10 have allowed us to incorporate several dramatic improvements in the MJS instrument. For example, the use of double-ended telescopes and the inclusion of a solid-state guard element permits a forty-fold increase in geometry factor. The dynamic range of the circuitry has been extended to include electrons through iron nuclei. A simple, lightweight rotating mechanism has been included so that precise angular distributions can be measured in the ecliptic plane.

Modes of Operation. A HET telescope has three basic modes of operation, two corresponding to particles that stop within the detector (denoted by S_1 and S_2) and one corresponding to particles that penetrate the detector (denoted by P). In the S_1 and S_2 modes the telescope operates in a standard dE/dx vs. E mode. The design of the instrument is, however, new and unique in that the detector stack serves double-duty. Both ends of the telescope are utilized for dE/dx vs. E measurements. In the S_1 mode we require a coincidence condition $A_1A_2\overline{C_4}\overline{G}$ (see trajectory 1, Fig. 7-1). A_1 and A_2 are identical silicon-surface-barrier detectors having small thicknesses in order to permit the measurement of low energy (> 4 MeV) particles. Each of these is constructed as a section of a spherical surface in order to minimize variations in the pathlength of particles traversing them. For particles that come to rest in A_2 (4 - 6 MeV/nuc) a two-parameter dE/dx vs. E analysis is performed. If a particle penetrates into the stack, a three-parameter double-dE/dx vs. E measurement is made. The combination $C_1 + C_2 + C_3$ provides the total-energy measurement up to an energy of 57 MeV.

In the S_2 mode (see trajectory 2, Fig. 7-1) the coincidence condition $B_1B_2\overline{C_1}\overline{G}$ is required. The B_1 and B_2 elements are 1.5 mm thick spherical lithium-drifted detectors. As with S_1, the low-energy particles that come to rest in B_2 (16 - 23 MeV/nuc) undergo two-parameter analysis, and higher-energy particles (23 - 68 MeV/nuc) undergo three-parameter double-dE/dx vs. E analysis. In this mode the total-energy measurement is accomplished using the linear combination $C_2 + C_3 + C_4$. The combination of the S_1

and S_2 modes then gives continuous coverage of the spectrum between 4 and 68 MeV/nuc with dE/dx vs. E analysis. In addition, significant overlap exists between the two stopping-particle modes so that the responses of the two ends of the telescope can be cross-checked.

In both the S_1 and S_2 modes isotopic resolution with $\Delta M = 1$ will be possible up to $Z = 8$ and resolution with $\Delta M = 2$ up to $Z = 16$. Resolution of adjacent charges is possible up to $Z = 30$. A detailed discussion of background and resolution is presented in Appendix A7-I.

In the S_2 mode precise measurements of the electron spectrum in the 3- 10 MeV interval will also be made. This will complement and overlap the measurements made by TET. Below 3 MeV, background due to Compton electrons from the spacecraft radioisotope power supplies will prohibit meaningful interplanetary electron measurements. Thresholds will be incorporated in the electronics to eliminate such background from the two parameter analysis modes.

In the P mode (see trajectory 3, Fig. 7-1) particles which penetrate the entire telescope are analyzed. In this mode detectors B_1, C_1, and $C_2 + C_3 + C_4$ are pulse-height analyzed, thus providing a triple dE/dx measurement. The low-energy threshold for protons in the P mode will be the energy required to penetrate the stack (68 MeV/nuc for protons and alphas). Between this energy and $\sim$ 150 MeV/nuc it will be possible to separate forward from backward moving particles by comparing the energy losses in B_1 and C_1. This then defines the upper energy limit for anisotropy measurement. Above 150 MeV/nuc the telescope becomes bi-directional. Because of the telescope's symmetry, however, the ambiguity in the particles' direction of incidence has no effect at all on spectral measurements above 150 MeV/nuc. In addition, the bi-directionality of the telescope in the P mode means that the geometry factor is effectively doubled. Accurate spectral measurements will then be possible up to at least 500 MeV/nuc and an integral point > 500 MeV/nuc will be determined.

Tables 7-I and 7-II present a summary of the properties of the three modes of analysis of the HET.

Table 7-I: HET Mode Characteristics

Mode	Type of Analysis	Proton Energy Range (MeV)	Coincidence Condition	Detectors Analyzed	Geometry Factor (cm^2-ster.)	View Angle
S_1	dE/dx vs. E	4 - 57	$A_1A_2\bar{C}_4\bar{G}$	$A_1, A_2, C_1+C_2+C_3$	2.0	60°
S_2	dE/dx vs. E	16 - 68	$B_1B_2\bar{C}_1\bar{G}$	$B_1, B_2, C_2+C_3+C_4$	1.8	60°
P	Triple dE/dx	68 - 500	$B_1B_2C_1$	$B_1, C_1, C_2+C_3+C_4$	2.0	46°

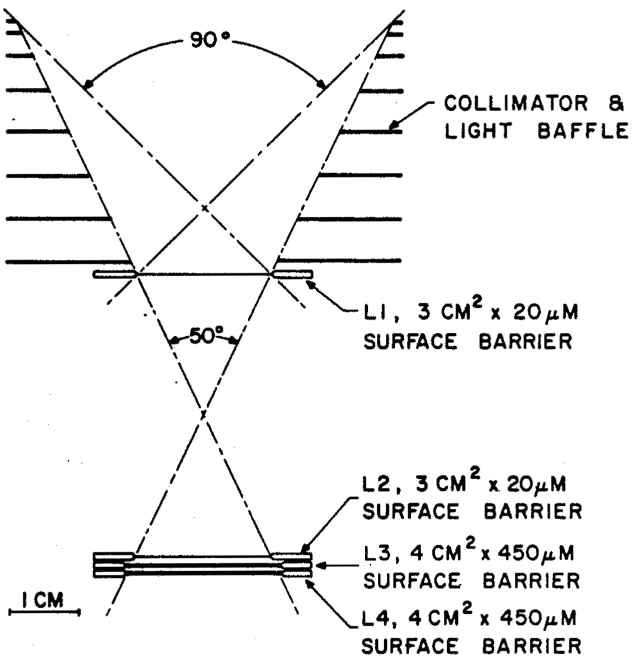
Table 7-II: HETS Galactic Cosmic-Ray Response

NUCLEUS	S MODE*					P MODE				
	Energy (MeV/nuc)	Events/Month		Min. Interstellar Anisotropy		Energy (MeV/nuc)	Events/Month		Min. Interstellar Anisotropy	
		1 AU	Inter-Stellar**	1 Mo.	1 Yr.		1 AU	Inter-Stellar**	1 Mo.	1 Yr.
H	4-68	4.7×10^4	1.5×10^6	0.4%	0.1%	> 68	4.1×10^6	7.2×10^6	0.3%	0.1%
He	4-68	1.9×10^4	8.6×10^4	1 %	0.3%	> 68	3.4×10^5	4.0×10^5	2 %	0.6%
Be	5.2-88	5.0×10^1	2.8×10^2	26 %	8 %	> 88	9.9×10^2	1.1×10^3	44 %	13 %
O	8.7-151	8.0×10^2	4.0×10^3	6 %	2 %	>151	9.1×10^3	1.0×10^4	10 %	3 %
Fe	13.5-287	1.8×10^2	7.0×10^2	16 %	5 %	>287	8.2×10^2	9.0×10^2	30 %	9 %

*$S = S_1 + S_2$
**Interstellar intensities are derived assuming a total-energy power-law spectrum.

The Guard Detector. The guard element G is a unique feature of the HET. It is shown as the shaded area in Fig. 7-1. The lithium-drifted detectors forming the stack are constructed in a double-grooved configuration so that the active area of the wafer is divided into two separate and independent areas. Each device then has a central circular active area surrounded by an annular guard ring. The G element is then the sum of the outputs of each of these guard rings. An anticoincidence shield is thus formed around the side of the stack without the necessity of the bulky and heavy photomultiplier-scintillator combinations used in the past. In the S modes the guard is used to actively reject events. In the P mode, however, because of the problem of knock-on electrons, the guard will not be used to reject events, but to tag them. A small version of the guard ring detector is now successfully in operation on board the Pioneer 10 spacecraft. The MJS version has successfully passed space-flight-qualification tests in the lab. A picture of such a device is shown in Fig. A7-1 of Appendix A7-I.

B. The Low-Energy Telescope System (LETS)



LOW ENERGY TELESCOPE (LET)

Fig. 7-2

General Description. The Low-Energy Telescope System (LETS) is designed to determine the flow patterns and to make high-resolution measurements of cosmic-ray nuclei ($1 \leq Z \leq 30$) down to very low energies. The major experimental problem is to achieve an adequate geometrical factor and to measure directional properties with sufficiently thin detectors so that multi-parameter analysis is possible down to the lowest possible energy. This is accomplished with 4 telescopes identical to the Low-Energy Telescope (LET) shown in Figure 7-2. The major new development has been the fabrication of large area, thin surface-barrier detectors. The Caltech group has previously flown a 3 cm^2 x 100 μm detector on OGO-6 and a 3 cm^2 x 50 μm detector will soon be launched on IMP-H. In addition, detectors as large as 4 cm^2 x 20 μm have been tested in the laboratory.

The four LET's will be oriented in the following directions: anti-Sun (+Z spacecraft coordinates), perpendicular to the ecliptic plane (approximately along +Y), and perpendicular to the spacecraft-sun line in the ecliptic (approximately +X and -X). This arrangement provides the triple advantage of anisotropy information, increased $A\Omega$ ($\sim$ 12 cm^2-sr total), and sensor redundancy.

Modes of Operation. Three basic modes of operation will be implemented, corresponding to single-, double-, and triple-parameter analysis.

In the single-parameter mode, only detector L_1 is penetrated by the particle. The acceptance cone is defined by the combination collimator and light baffle, resulting in a geometrical factor ($A\Omega$) of $\sim$ 3 cm^2-sr and a maximum angle of incidence of 45° with respect to the telescope axis. In this mode only hydrogen (0.15 - 10 MeV) and helium (0.35 - 20 MeV/nuc) nuclei will be prominent enough so that fluxes can be determined in the presence of the higher-energy, higher-Z penetrating nuclei. The primary advantages of this mode are the low-energy thresholds and the large $A\Omega$ which permit determination of anisotropies as small as 1% in one month (based on 3σ difference in the counting rates of two telescopes).

Complete characteristics of this mode are included in Table 7-III. In this table, the flux at 1 AU is based on 1966 spectra, assuming that dJ/dE is constant below 10 MeV/nuc. Any solar contribution will increase this rate. The interstellar flux assumes a total energy power law (dJ/dE $\sim W^{-2.65}$), normalized to the high energy (unmodulated) spectra at Earth. A less conservative estimate would considerably enhance the event rate.

In the double-parameter mode, characterized by $L_1L_2\bar{L}_3$ the particle energy loss is determined in L_1 and the total energy is the sum of L_1 and L_2. The dE/dx-E analysis provides unambiguous particle identification, with isotope resolution through Be and elemental resolution through Fe. The very thin L_1 detector makes this mode possible down to $\sim$ 1.1 MeV for hydrogen, with the threshold only $\sim$ 2.5 MeV/nuc for Fe. Detailed characteristics are included in Table 7-III.

In the triple-parameter mode ($L_1L_2L_3\bar{L}_4$), the particle's energy-loss is measured twice in the identical L_1 and L_2 detectors, and the residual energy is measured in L_3 which is 450 μm thick. The advantage of the double-dE/dx measurement is discussed in Appendix A7-I. The resolution and background rejection will be similar to that achieved in the HET. The threshold energy for this mode is as low as possible (1.8 MeV for H, 4.8 MeV/nuc for Fe), while the upper limit (8 MeV for H, 30 MeV/nuc for Fe) provides significant overlap with the HET energy range. Table 7-III provides further details.

Table 7-III: LETS Galactic Cosmic-Ray Response

	Kinetic Energy (MeV/nuc)			Events/Year		Minimum Interstellar Anisotropy	
Nucleus	Single*	Double*	Triple*	@ 1 AU	Inter-stellar	1 Mo.	1 Yr.
H	0.15-10			$9.6x10^4$	$4.2x10^6$	1%	0.4%
He	0.35-14			$4.6x10^4$	$3.2x10^5$	4%	1 %
H		1.1-1.8	1.8-8	$1.3x10^4$	$5.7x10^5$	3%	1 %
He		1.1-1.8	1.8-8	$4.5x10^3$	$3.1x10^4$	12%	3 %
Be		1.2-2.2	2.2-11	19	130		
C		1.7-2.9	2.9-15	290	2000		13 %
O		1.9-3.4	3.4-18	300	2100		13 %
Mg		2.1-3.8	3.8-22	77	540		
Ca		2.5-4.7	4.7-28	15	100		
Fe		2.5-4.8	4.8-30	56	400		30 %

*Single, double, and triple parameter analysis
Total geometric factors: 12 cm^2-sr (single parameter)
2 cm^2-sr (double and triple)

Table 7-IV: Model Trapped Fluxes at Jupiter

Distance	Proton Flux (cm^{-2}-sec^{-1})		Spectral Peak (MeV)	
(R_j)	Nominal	Max	Nominal	Max
6	$7.5x10^3$	$1.4x10^7$	2.3	3.9
7	$3.5x10^3$	$1.0x10^7$	1.5	2.5
10	$4.0x10^2$	$3.2x10^6$	0.54	0.92
15	28	$1.1x10^7$	0.17	0.29
20	2.6	$1.7x10^6$	0.075	0.13
25	0.2	$2.4x10^5$	0.04	0.07

Trapped Radiation Response. With the configuration discussed above, a LET will analyze 0.15 to 8 MeV trapped protons and heavier nuclei with intensities up to at least 10^4 cm^{-2} sec^{-1}. As shown in Table 7-IV, this dynamic range is ideally matched to the nominal model of Jovian trapped protons, encompassing the flux and the energy of the spectral peak at periapsis. Should Pioneer 10 indicate a larger trapped intensity, substitution of readily available, smaller detectors and minor changes in the amplifiers can easily be made to one LET so that intensities up to at least 10^8 cm^{-2} sec^{-1} can be measured. This modification would extend the dynamic range to include the upper-limit-model spectrum (see Table 7-IV). The LET measurements will be complemented by the HET and TET outside 10 R_J, based on the nominal Jupiter workshop model.

It should be pointed out that we do not measure electrons below 1 MeV and nuclei below 0.15 MeV. We consider these to be of sufficient importance that they should be measured on the MJS missions. We would consider sharing our data system during the encounter phase since this would allow addition of complementary detectors at significant savings in weight, power and cost.

Background Effects. The background effects are minimized by several techniques. The 20 μm detectors are insensitive to minimum-ionizing electrons and hydrogen. A normally incident nucleus must have $Z \geq 5$ to be detected. The maximum electron sensitivity for L_1 events is $< 10^{-3}$ at the 150 keV threshold, decreasing to a factor of 10 by 200 keV. For L_1L_2 coincidence, the sensitivity is $\ll 10^{-6}$ at the 300 keV threshold, and decreasing rapidly with increasing energy.

C. Priority System and Memory for HETS and LETS

During the course of the MJS mission there will be many situations where the telescope event rate will be larger than the spacecraft telemetry system can handle. When this happens, the experiment can only sample a portion of the incoming particle beam. We will include in the experiment electronics a priority system to bias the sample towards the rarer and more interesting events that occur in the telescope. Rates will be monitored corresponding to each event type so that during high-intensity periods absolute spectra can still be determined. The ordering of the priority system will be varied as a function of time so that no single event type will dominate. Systems nearly identical to that described above have been successfully flown on both the IMP VI and Pioneer 10 spacecraft.

Also during the mission (especially the later portion) tracking coverage will not be continuous. To improve the statistics of the rare species (e.g., Be and Fe) a memory is desirable to store rare events selected by the priority system. With a small memory capable of storing 500 events we will be able to accumulate practically all such events occurring during a one week interval.

D. The Electron Telescope (TET)

General Description/Mode of Operation. We have been able to design, test, and calibrate a relatively simple, small, and light-weight electron energy-spectrometer for the crucial energy range from about 5 MeV to 110 MeV. The use of novel integral detector-guarding devices allows an all-solid-state detector design with adequate energy resolution and background rejection, so that meaningful spectra can be measured even at the relatively low electron intensities near Earth. The response of the electron telescope, including the effects of background, have been verified by accelerator calibrations of a prototype model and by Monte-Carlo calculations.

Figure 7-3 gives a schematic cross section of the proposed electron telescope along with a summary of instrument parameters. The telescope consists of eight solid-state detectors (D_1 - D_8) and six tungsten absorbers (A_1 - A_6) in a cylindrical geometry. The detector-absorber stack is surrounded by a grid of solid-state-guard detectors (G_2 - G_8) which replace the conventional bulky scintillator-photomultiplier guard counter.

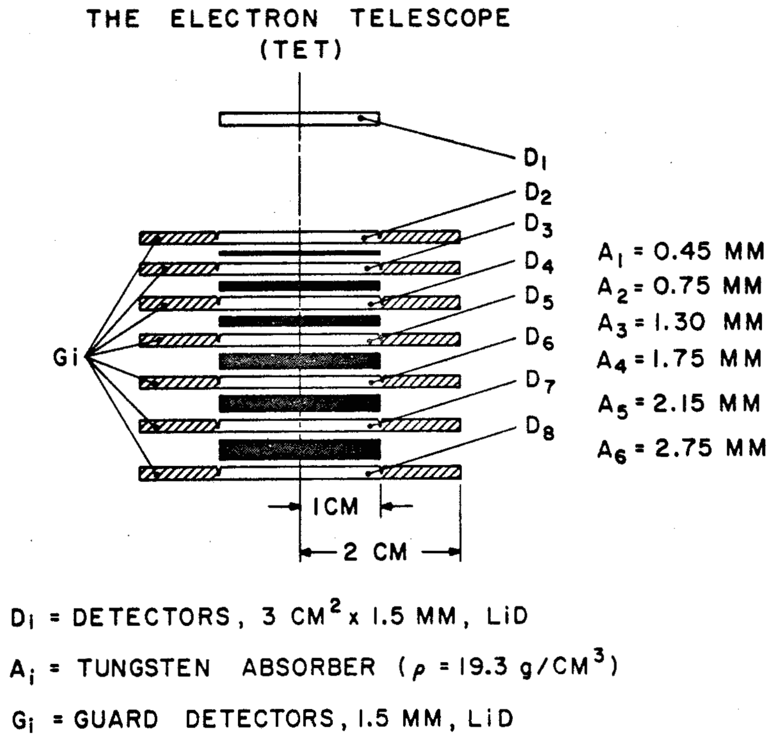


Fig. 7-3.

Electrons and their energies are identified by a double-dE/dx measurement in detectors D_1 and D_2 and by a simultaneous measurement of their range, as determined by the penetration of detectors D_3 through D_7. The use of range spectroscopy, while providing satisfactory energy resolution and background rejection (see below), has the additional virtue of being insensitive to electronic gain drifts which may arise in MJS-type long-term missions. The CIT laboratory has over a decade of experience with dE/dx-range-type spectrometers, and has successfully flown such devices on the OGO-VI satellite and in balloon operations.

Energy Resolution/Background Effects. Thorough energy calibrations of prototypes of electron range-telescopes for energies from 1 MeV to 1 GeV have been performed on particle accelerators (see Appendix A7-II). These data allow the unfolding of energy spectra from measured range distributions with accuracy comparable to that achieved using total-absorption spectrometers. As an example, we show in Table 7-V the expected range distributions (determined from the calibrated detector response) for the three typical electron energy spectra shown in Figure 7-4. The application of a simple unfolding technique to these data results in the very satisfactory reproduction of the input spectra shown by the TET data points in Figure 7-4. Figure 7-4 also includes the expected data points from the HET telescopes, showing the adequate overlap of energy ranges for TET and HET.

The dashed areas in Figure 7-4 indicate conservative estimates of maximum background levels during the mission, which are caused by the spacecraft RTG's (below ~ 2.5 MeV) or by interacting high-energy protons in the detector stack. The RTG background levels are obtained from direct calibrations of the GSFC/UNH Pioneer 10 telescope. The basic $D_1D_2D_3$ coincidence requirement, which includes the absorber A_1, makes TET insensitive to RTG-background. The proton induced background (above ~ 2.5 MeV) has been calculated by Monte-Carlo techniques for the maximum flux levels of primary cosmic rays during the MJS missions. The Monte-Carlo programs and the nuclear cross sections used in the calculations have been

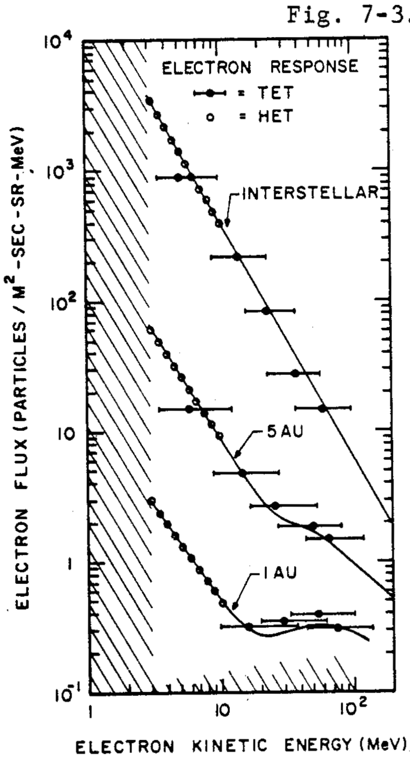


Fig. 7-4. Typical electron spectra (solid lines) for heliocentric radii of 1 AU, 5 AU, and the interstellar medium. Data points show the resolving power of the HET and TET.

successfully applied by the Caltech laboratory to other cosmic-ray telescopes with extensive verifications on particle accelerators and in nature. Definitive electron energy spectra can be measured for all phases of the MJS missions (see Fig. 7-4, Table 7-V) without significant background interference.

Table 7-V: Telescope range distributions and maximum background levels for three typical cosmic-ray electron spectra shown in Fig. 7-4. (See App. A7-II for details)

Range (D_i's triggered)	Geometry Factor (cm^2-sr)	Counts/month			
		1 AU	5 AU	Interstellar	Max. Background
$D_1D_2D_3$	1.8	$1.8x10^3$	$3.4x10^4$	$1.6x10^6$	$3.9x10^2$
$D_1 \ldots D_4$	1.4	$1.6x10^3$	$1.6x10^4$	$5.2x10^5$	$5.2x10^2$
$D_1 \ldots D_5$	1.0	$1.4x10^3$	$8.6x10^3$	$1.7x10^5$	$5.2x10^2$
$D_1 \ldots D_6$	0.8	$1.4x10^3$	$6.0x10^3$	$7.3x10^4$	$5.2x10^2$
$D_1 \ldots D_7$	0.6	$1.4x10^3$	$4.9x10^3$	$4.2x10^4$	$7.8x10^2$

E. Data Analysis

Initial routine processing of the data will be performed on the 360/75 computer at Goddard. The Goddard Pioneer 10 programs have in general been written in a modularized form. It is anticipated that our MJS data reduction system with its many similarities to Pioneer 10 will make extensive use of these program modules. The Goddard programs will reformat and compress the data onto a new set of magnetic tapes. Copies of these tapes will then be forwarded to the participating institutions. While each institution will have well defined responsibilities for analysis of specific portions of the data, the initial papers will represent a joint effort of all seven investigators.

II. Electronic Instrumentation

Introduction and Philosophy: All of the electronic circuitry we are proposing is taken directly from, or is very similar to, both that on the GSFC/UNH experiment on Pioneer 10/G and the GSFC/CSIRO experiment on Helios A/B. All parts and methods proposed are likewise parts which meet Pioneer, GSFC and Helios reliability requirements and which have passed thorough screening programs. The parts in the linear systems, including preamps/amps, threshold circuitry, decision logic, pulse-height analyzers, power supplies, etc., have also qualified for manned space rating, and a system will fly on ATM. Similar circuitry on OGO, IMP and Pioneer G have already demonstrated lifetimes of detectors and electronics for periods comparable with the proposed MJS mission. Thus, the performance of the system can be accurately predicted, and one can have great confidence in the weight, power, cost and schedule estimates.

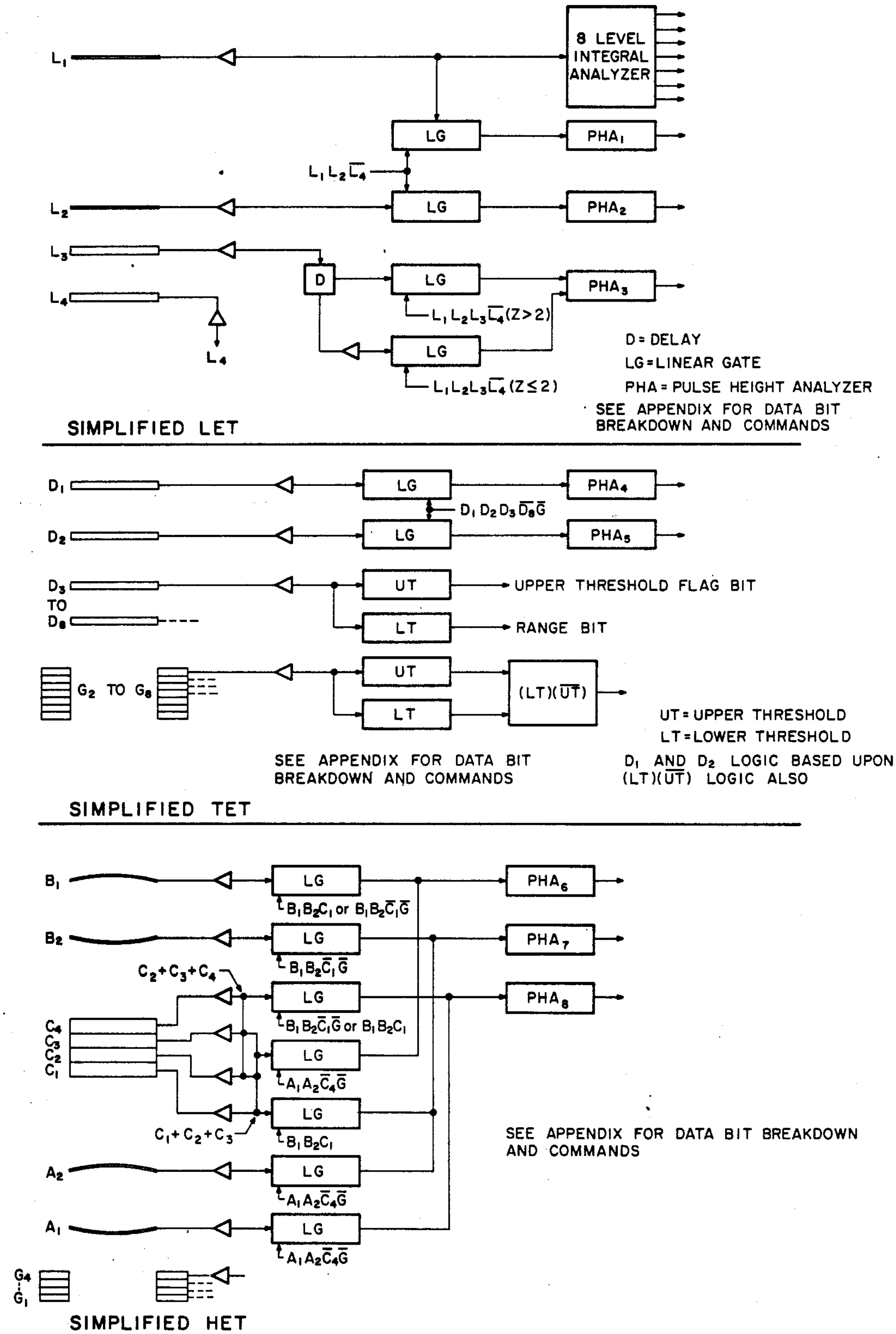
Our design philosophy revolves about systems and circuits which have a demonstrated performance and reliability in similar environments. Using reliability studies of our Pioneer instrumentation and with the redundancy schemes we propose here, we believe the instrument will have an operating lifetime in excess of five years at a 95% confidence level. The High-Energy Telescope System (HETS) has 2 telescopes, each with its own electronics system. One of these telescopes can be rotated from 0° to 90° and 180°, both to measure anisotropies and to intercalibrate the telescopes (the only way it can be done with the required accuracy). The HETS electronics systems downstream of the preamp/amplifiers can be cross-strapped by command so that HET #1 feeds the HET #2 electronics, etc. In this way one or both of the HET telescopes can drive either PHA/data system in an on-board, two-shared mode. Similarly, the LETS provides redundancy as well as measuring anisotropies and pitch-angle distributions. The use of the GSFC custom-designed family of P-channel, LSI MOSFET circuits is ideal for this application, since it allows a reliable data system with low weight and power consumption, which accomodates 8 pulse-height analyzers and 64 rate-counting channels simultaneously. The system design features many parallel paths and command control, so that even a component failure is unlikely to affect other than a small part of the experiment. Thus, we are dealing with a familiar system which has a demonstrated reliability.

Solid-State Detectors: This experiment uses both silicon surface-barrier detectors and lithium-drifted silicon detectors. Investigators from all three institutions have had extensive experience with these devices over the past 10 years. Well-instrumented laboratories exist for the testing and qualification of these devices for space flight. The lifetime of these solid-state detectors on these missions will be determined by radiation damage effects alone. The fluences of electrons and protons identified in Table G-2 of the appendix to the proposal instructions are about two orders of magnitude below the point where the damage effects begin to be a problem for our detectors. However, there is no specification for lower-energy protons, in the range 100 KeV to a few MeV, for instance, and the effects of these particles are most important for exposed systems such as the outermost elements in a telescope. Our detectors are able to tolerate 10^{14} to 10^{18} p/cm^2 depending upon the spectral shape and detector thickness.

The RTG neutron fluence design requirement for the MJS spacecraft is $< 10^{10}$ p/cm^2 ($E_n \sim 2.5$ MeV) and is near to the tolerable limit for our lithium-drifted silicon detectors operated in the high bias region ($\sim$ 200 volts per mm). We have always used these high bias detectors despite a serious cost penalty, and the results published by the Electron Devices Section, National Bureau of Standards in the past two years have clearly shown the value of this conservatism. Low bias detectors (50 to 100 volts per mm) are able to tolerate only about 10^9n/cm^2 before the damage effects are apparent. These effects are insidious for analytical nuclear-particle experiments, because a serious reduction in charge collection efficiency (due to trapping) occurs long before increases in leakage current or noise become a problem.

Electronics System: The fundamental operation of each of the telescope systems has already been discussed in Section 7.I. Figure 7-5 shows simplified block diagrams of a HET, LET and TET electronics system. The rate outputs and cross-strapping provisions have been left out of the diagrams for clarity. Basically the charge collected in the solid-state detector is converted to a voltage pulse in a charge-sensitive preamplifier; amplified and shaped; applied to various threshold circuits; logical conditions are formed; a comparison is made with any event not yet read into telemetry and the existing priority condition; the appropriate linear gates are opened to enable pulse-height analysis; and the addresses are then stored in the data system with their auxiliary bits awaiting readout. In parallel to the above, the large number of logical rates are being summed per readout interval in 24-bit registers in the data system and log-compressed for telemetry readout. The construction of the linear, decision-making and PHA circuitry is predominantly with discrete components on small hybrid substrates. The command and control circuitry is a mixture of hybrid bipolar and T^2L logic of the 54L series. The processing data system uses custom LSI MOSFET circuits (AMI).

Performance: The most demanding requirement placed upon the instrumentation is the large dynamic range required, especially in HETS. This is accomplished by using our existing pulse-height analyzer with a full scale range of 4096, and gain switch-



SIMPLIFIED BLOCK DIAGRAMS OF HET, LET & TET ELECTRONICS SYSTEMS

FIGURE 7-5

ing charge-sensitive preamplifiers. The PHA system has an integral linearity of $\sim 0.1\%$ and a differential linearity of $\leqslant 2\ \%$. Gain switching in the preamp is accomplished by switching the feedback capacitor by a factor of 4 or 8 as is appropriate for that detector. The LETS uses two different gain paths in the post-amplifier for detector L_3 corresponding to particles with $Z > 2$ and $Z \leq 2$. The latter decision is made by forming a linear sum of L_1, L_2, and L_3 and applying the sum pulse to a threshold discriminator. These systems built for Pioneer 10/G and Helios have demonstrated a stable performance over the temperature range from -40°C to +60°C. An upper thermal limit of +35°C is set by the solid-state detectors, since their performance lifetimes cannot be guaranteed at high temperatures.

Rotation Mechanism: We have built and tested at GSFC the device proposed here. It is very similar to the rotation mechanisms used for the past 10 years on IMP. Thermal expansion of an organic material is used to drive a sealed piston/shaft in one-dimensional motion against a spring. The shaft drives a rack gear which is meshed with a pinion gear, producing rotary motion. Stops are provided at 90° and 180° using detents and microswitches. Applying power beyond 180° results in the detents being retracted until the system returns to 0°. A test system in vacuum requires 5 watts for ~ 10 minutes to accomplish 180° rotation. For the MJS mission we plan a commandable cycle rate which would allow cycles from perhaps 4 per day down to 1 every 4 days in a binary sequence. The system has an average power consumption near zero, obviously, is non-magnetic and has already shown lifetimes greater than 5 years on a single IMP. The design and action is very positive, since the shaft can develop up to 35 pounds of force.

Weight and Power: Analyses are summarized in the Appendix A7-III leading to a weight estimate of 4.45 Kg and 4.8 watts assuming 80% efficiency for the AC/DC conversion.

Configuration: Consistent with the JPL literature, we envision the entire experiment being mounted in the cruise-science area near the edge of the dish. The telescopes and preamplifiers are mounted on top of an electronics box of approximately 30 cm x 30 cm x 20 cm. The overall height will be 35 cm high and will allow the telescope systems to look or scan in the ecliptic plane with the exception of one LET which looks normal to the plane.

Data Storage Option: Considering the planned telemetry coverage, data storage for rare events is highly desirable for this experiment. Considering further that one may indeed go as long as a week in some instances between telemetry contacts, a minimum memory size of 500 events of 45 bits each is required. If this storage is not available on the spacecraft, it could be included with this experiment as part of our data system. Implementing the storage with our present P-channel MOS techniques, 16 45-bit words with control circuitry could be put on one chip. Thus 32 integrated circuits could provide storage of 512 rare events at a cost of about 180 grams and 500 mw of secondary power.

8,9,10: Principal Investigator and Co-Investigator Responsibility, Commitment, Relevant Scientific Experience and Biographical Information.

A brief summary of these items are given below. They are covered in much greater detail in the Management Section and in Appendix A10-I. It is assumed that the data analysis and systems design will be shared among all seven investigators. This will be the major research commitment of all seven individuals.

J. R. Jokipii (32) Associate Professor of Theoretical Physics, CIT. Theory of cosmic-ray propagation in solar wind and galaxy. Astrophysical plasma physics and radio astronomy. Coordinates theoretical work related to experiment development and analysis.

F. B. McDonald (47) Head, Laboratory for High Energy Astrophysics, GSFC, and Professor of Physics (P.T.) University of Maryland. Studies of Galactic and Solar Cosmic Rays. Principal Investigator for Cosmic Ray Experiments flown on Exp. XII, XIV, IMPS I-VI, OGO I, III, V, Pioneer 10. Will be concerned with design of HET System.

E. C. Stone (36) Associate Professor of Physics, CIT. Solar and Galactic Cosmic Rays, Energetic Particles in the Magnetosphere. Co-investigator on Discover 31, 36, OGO II and IV, HEAO A. Cosmic-ray experiments and P.I. on OGO VI, IMPS H and J. Primary responsibility for LET.

B. J. Teegarden (32) Physicist, Laboratory for High Energy Astrophysics, GSFC. Cosmic-Ray Studies. Co. I. on Goddard Cosmic Ray Experiment on OGO I, III, V, IMP's IV and V, Pioneers 10 & G. Will have primary responsibility for HET design.

J. Trainor (37) Head, Laboratory for High Energy Astrophysics, Instrumentation Branch. Electronics, trapped radiation, solar and galactic cosmic rays. Co. I. on IMP V, H and J, Pioneer 10 and G, P. I. Helios A and B cosmic ray experiment. Responsible for electronics and mechanical systems.

R. E. Vogt (42) Professor of Physics, CIT. Research on the astrophysical aspects of cosmic radiation. Co. I. on cosmic-ray experiments on OGO VI, IMP H and J and HEAO A. Principal Investigator and will have primary responsibility for the TET development.

W. R. Webber (43) Professor of Physics and Director of Space Science Center, University of New Hampshire. Galactic and solar cosmic-ray studies. P.I. on cosmic ray experiments flown on OGO II and IV, Pioneer 8 and 9, Co. I. on Pioneer 10. Will be concerned with the design of HET and TET.

Appendix A7-I

BACKGROUND AND RESOLUTION

Detector background in this discussion is defined as the randomly distributed events which characteristically appear in any plot of dE/dx vs. E data. Detector resolution is defined simply as the percentage width of a dE/dx vs. E track. The optimization of both of these quantities is important if one is to be able to perform isotopic analysis and to separate the closely spaced tracks of the heavy elements.

Detector background is predominantly produced by particles which undergo catastrophic nuclear interactions within the thick stack (C_1-C_4). Low-energy secondary produces can be produced which exit through the dE/dx elements and masquerade as heavy particles. A redundant dE/dx measurement is an extremely valuable tool in rejecting this kind of background. Such slow moving secondary products would, in general, not be expected to produce identical outputs in the dE/dx elements and would be eliminated by the application of a consistency criterion. Evidence in support of this conclusion is shown in Fig. A7-2. This is data taken from the Goddard - Univ. of New Hampshire cosmic ray experiment on the Pioneer 10 spacecraft. The Pioneer 10 telescope is similar to the MJS HET, with the one important exception that no guard-ring detectors were used. Background on Pioneer 10 is rejected only by the use of double-dE/dx and range criteria. The data shown is a plot of the output of the front element vs. the output of the stack. The prominent line is due to quiet-time alpha particles. The signal-to-background ratio in this data is remarkably good. ^3He and ^4He will be easily resolvable. Also the light element region above the alpha line is almost completely background free. We emphasize that our MJS High-Energy Telescope will be significantly better than this due to the use of guard ring detectors.

The fact that the HET is built entirely out of solid-state detectors eliminates a number of problems associated with telescopes using scintillators. Light collection non-uniformities as well as non-linearities in the light output as a function of energy loss are not a problem with solid state detectors. The HET will be capable of resolving isotopes at least as far as ^{14}N and ^{15}N. The ^{14}N and ^{15}N tracks are separated by 5.3% in the dE/dx coordinate. Pathlength variations and Landau fluctuations will each be less than 2% (FWHM) over the S_2 range in the HET. Detector + preamp noise will be less than 100 KeV FWHM in the dE/dx elements. Since the minimum energy loss in the B_1 element for a ^{14}N nucleus is 82 MeV, the detector + preamp noise contribution will be less than 0.2% . Since the above effects add quadratically, the total track width for ^{12}C will therefore be less than 3% which will permit the separation of ^{12}C and ^{13}C over the entire S_2 range of the HET.

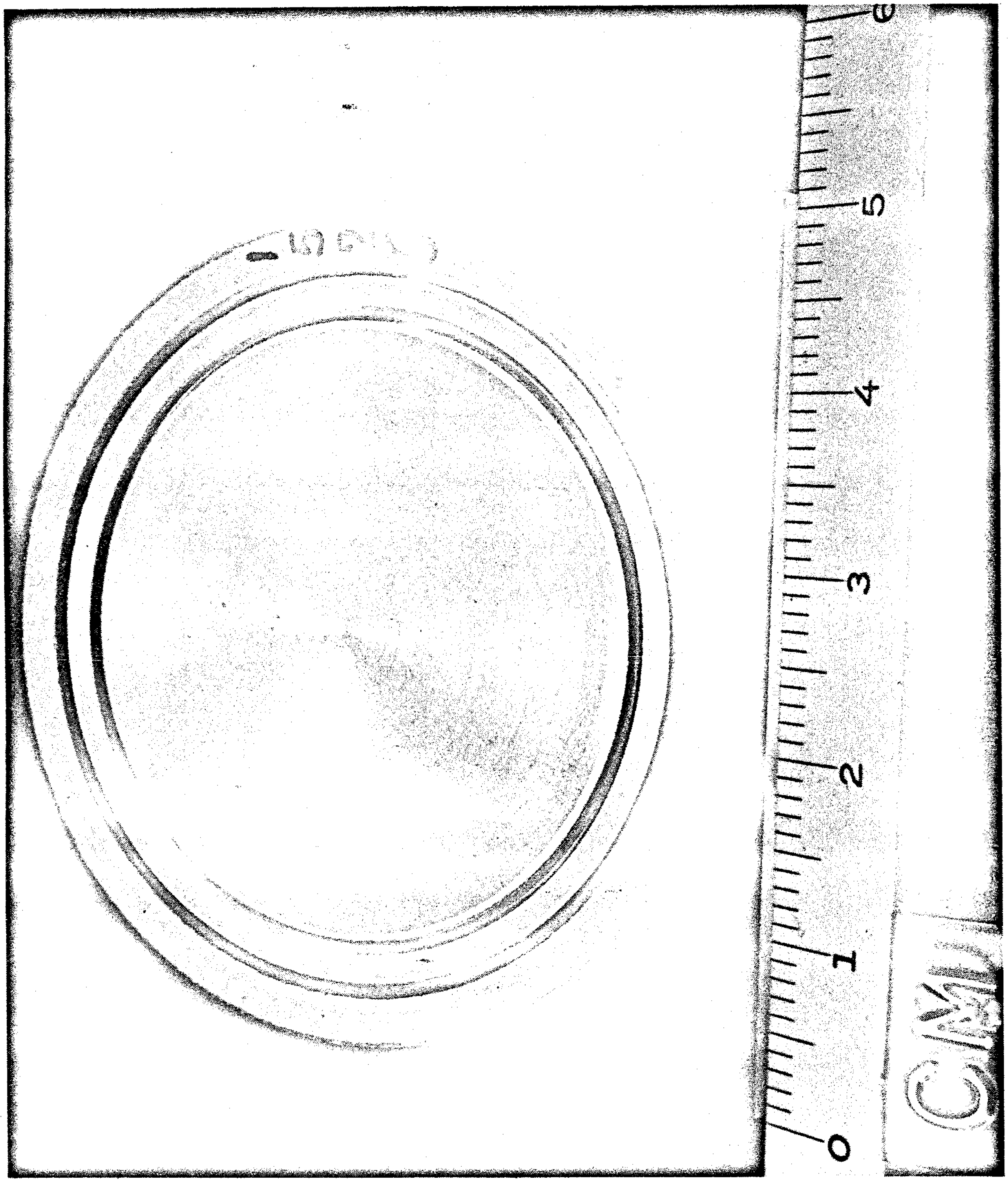


FIGURE A7-I
GUARD RING DETECTOR

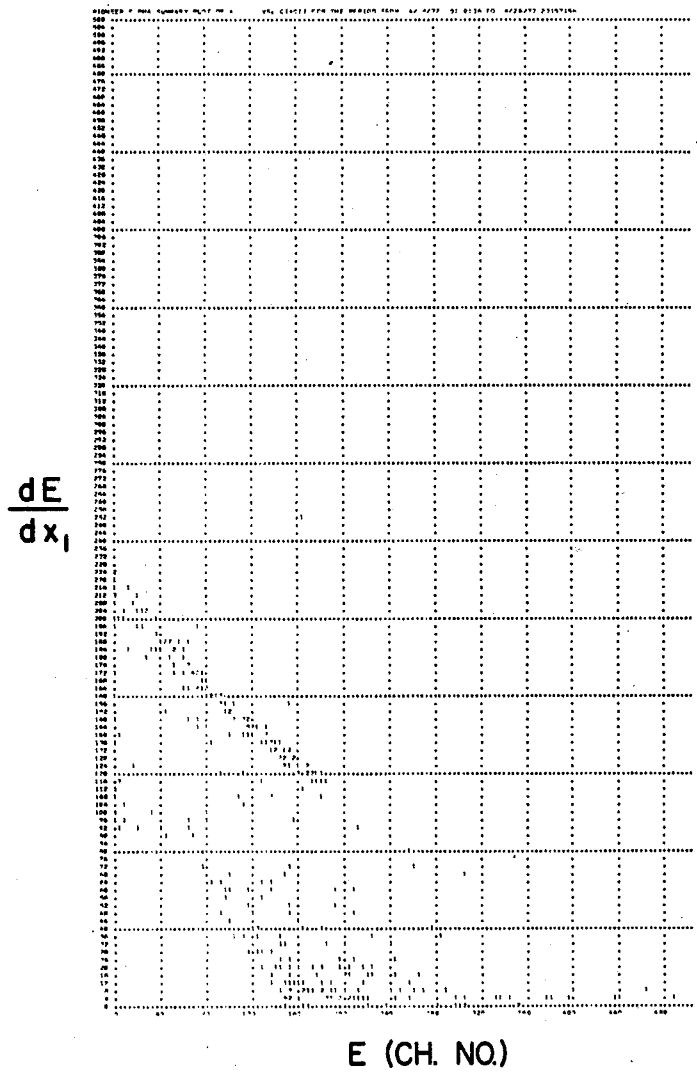


FIGURE A7-2

PIONEER 10 dE/dx VS. E DATA

Appendix A7-II

1. Electron-Telescope (TET) Calibrations

Fig. A7-3 shows the electron-calibration results for a dE/dx-range prototype telescope. Data between 5 MeV and 70 MeV were obtained in July 1972 at the NRL electron accelerator, while the calibration data above 70 MeV are based on earlier studies with the Caltech electron synchrotron.

The calibration data apply to the telescope specified in the inset of Fig. A7-3, which is almost identical to the proposed MJS electron telescope.

The data shown in Fig. A7-3 are response curves of the telescope to mono-energetic electron beams, indicating the fractional distribution of these electrons over the telescope ranges. These response curves show an equivalent energy resolution which is comparable in quality to those of total-energy-absorption type devices. The response curves form the basis of a conversion matrix which is used to unfold energy spectra from range distributions, as illustrated in Figure 7-4 and Table 7-V.

2. Typical Electron Energy Spectra At 1 AU, 5 AU, And The Interstellar Medium For The MJS Missions.

The three energy spectra used in Figure 7-4 and Table 7-V for illustration purposes represent realistic estimates for the MJS missions.

The interstellar electron spectrum (IS) shown is based upon the galactic non-thermal radio spectrum for energies above several hundred MeV and represents a power-law extrapolation at lower energies. The spectra shown for 5 AU, and 1 AU have been derived from the interstellar spectrum by use of numerical solutions of the cosmic-ray transport equation using accepted values for the solar wind velocity and the cosmic-ray diffusion coefficients. In addition, the calculated electron spectrum at 1 AU agrees with observational results. The 1 AU spectrum shown may be considered typical for the expected electron fluxes at the beginning of the MJS '77 missions.

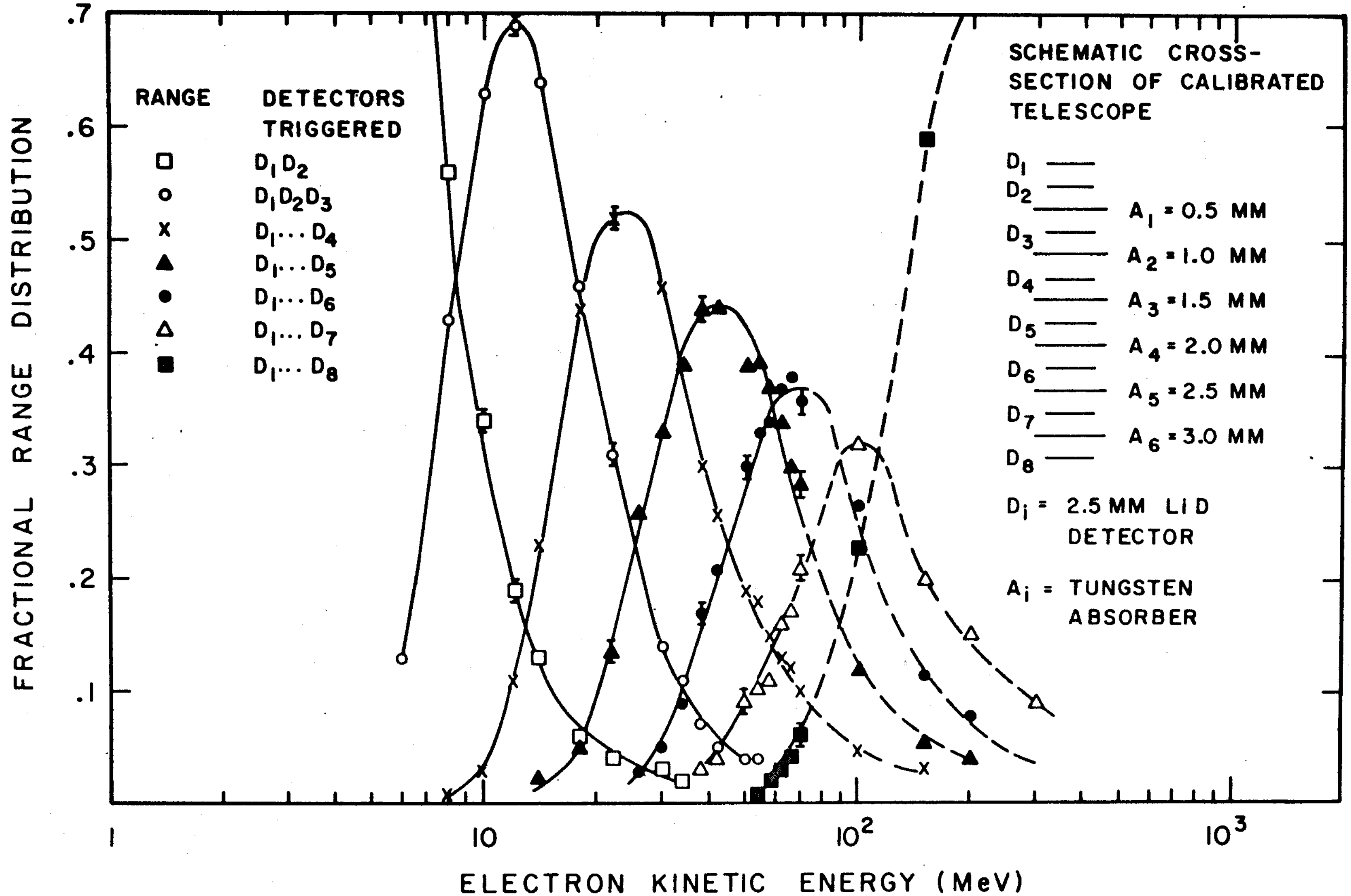


Figure A7-3. Electron-calibration results for prototype TET shown in inset. The response surves shown represent the fractional distribution of mono-energetic electrons over the telescope ranges.

Appendix A7-III

INSTRUMENTATION DETAILS

LETS

Thresholds: L_1 150 KeV
L_2 150 KeV
L_3 200 KeV
L_4 200 KeV

4096 channel pulse height analyzers

4 levels of priority

10 command bits to allow removing a LET from the system; logic control; overriding priority; and stepping the priority to a given level.

One would monitor a total of 48 logical rates from the 4 LET.

A single PHA event requires 44 bits as follows:

36 bits =	3 PHA addresses of 12 bits
2 bits	HET/LET/TET ID
2 bits	LET ID
2 bits	priority mode
1 bit	L_3 gain
1 bit	logic mode

All other information is given in the subcommutated telemetry.

TET

Thresholds: all channels 200 KeV

Pulse height analyzers: 128 channels

No priority system

9 command bits to allow changing D_8 from an anti to a range bit; disable-G logic; and the relaxation of individual G_i requirements. The above are largely required for test.

A maximum of 16 rates would be monitored.

A single PHA event requires 30 bits as follows:

14 bits	2 PHA addresses of 7 bits
6 bits	range bits
6 bits	range upper level flag
1 bit	D_8 disable
1 bit	G disable
2 bits	G event ID.

HETS

Thresholds:	A	100 KeV
	B	100 KeV
	C_1	300 KeV
	C_{2-4}	1 MeV

Pulse height analyzer: 4096 channels

4 levels of priority

11 command bits for enable electronic calibration; reverse PHA/telescope connections; connect both telescopes to either PHA electronics set; override priority; lock in a priority step; lock in a gain step; or disable individual G_i.

A single PHA event requires 45 bits as follows:

36 bits	3 PHA addresses of 12 bits
2 bits	HET/LET/TET ID
2 bits	priority condition
1 bit	gain step
2 bits	mode ID
2 bits	C range

All other information is given in the subcommutated telemetry.

WEIGHT BREAKDOWN

LET telescopes (4)	294 g.
linear electronics	253
PHA and logic system	472
TET telescope (1)	205
linear electronics	143
PHA and logic system	210
HET telescopes (2)	255
linear electronics	520
PHA and logic system	715
Rotation drive and mechanism	150
Data Systems	605
Power Supplies	215
Mech. System and interconnect	415
	4452 grams,

512 x 45 bit storage option	180 grams.

POWER BREAKDOWN

HETS	1304 mw
LETS	636
TET	355
Interface Data System	240
MOSFET Data System	1230
Detector Bias Supplies	75
	3.84 watts

Assuming 80% efficiency in the AC/DC power converter/conditioner, the total primary power required is 4.8 watts.

APPENDIX A10-I
BIBLIOGRAPHIES AND BIOGRAPHICAL INFORMATION

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EDUCATION:	1961 - B.S. (honors) University of Michigan Ann Arbor
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PREVIOUS POSITIONS:	1960 - 1961: Summer Research Assistant, Argonne Laboratory
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	1963 : Visitor, High Altitude Observatory
	1961 - 1970: Consultant, RAND Corporation
	1964 - 1965: Teaching Assistant in Physics, California Institute of Technology
	1965 - 1967: Research Associate, University of Chicago
	1967 - 1969: Assistant Professor of Physics, University of Chicago
	1969 : Visiting Researcher, Max-Planck-Institute for Extraterrestrial Physics, Munich, West Germany
PROFESSIONAL SOCIETY MEMBERSHIPS:	American Astronomical Society American Geophysical Union American Physical Society Phi Beta Kappa Phi Kappa Phi Phi Eta Sigma Sigma Xi
AWARDS:	Woodrow Wilson Fellow, 1961 Alfred P. Sloan Foundation Fellow, 1969 -

PUBLICATIONS:

"Distribution of Gases in the Protoplanetary Nebula", Icarus 3, 248 (1964).

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"Propagation of Cosmic Rays in a Random Magnetic Field", Midwest Cosmic Ray Conference, Iowa City, Iowa, 1968

"Anisotropies and Confinement of Cosmic Rays in the Galaxy", Midwest Cosmic Ray Conference, Baton Rouge, La., 1969.

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"Cosmic-Ray Acceleration: Recent Observational and Theoretical Results", Washington Meeting of the American Physical Society, 1971.

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DATE OF BIRTH:	May 28, 1925
PRESENT POSITION:	Chief, Laboratory for High Energy Astrophysics
RESEARCH AREA EXPERIENCE:	Solar cosmic rays, energetic particles, space radiation
EDUCATION:	1948 - B.S. Duke University 1951 - M.S. U. of Minnesota 1955 - Ph.D. Physics & Math, Univ. of Minnesota
PREVIOUS POSITIONS:	1951 - 1953 Pre-doctoral Fellowship, Atomic Energy Comm., Oak Ridge 1953 - 1956 Res. Assoc., State U. of Iowa 1956 - 1959 Assist. Prof. Physics, SUI 1959 - present Goddard Space Flight Center 1964 - 1966 Assoc. Ed. of Geophysical Res.
OTHER POSITIONS:	1963 - present Part-time Professor of Physics, University of Maryland
PROFESSIONAL SOCIETY MEMBERSHIPS:	American Physical Society (Fellow) American Geophysical Union Washington Philosophical Society SigmaXI Phi Beta Kappa American Astronomical Society
AWARDS:	NASA Award for Exceptional Scientific Achievement - 1964 Presidential Management Improvement Certificate, 1971
GSFC PROJECTS:	Principal Investigator on experiments flown on Exp. XII, XIV; IMP I-V; OGO I, III, V, & IMP H,I,J; Pioneer F & G; and Helios A, B. Project Scientist: Explorer XII, XIV, IMP I, II, III, IV, V & VI; EGO & SAS during early definitive stages; HEAO
COMMITTEES:	Fields and Particles Subcommittee Astronomy Subcommittee Organizing Committee, Div. of Cosmic Physics, American Physical Society Cosmic Ray Panel - Astronomy Mission Board

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RESEARCH AREA EXPERIENCE:	Solar and galactic cosmic rays, energetic particles in the magnetosphere. Investigator on Discoverer 31 and 36, Co-investigator on OGO-II and IV, principal investigator on OGO-VI, IMP-H and J, and Co-principal investigator on HEAO-A
EDUCATION:	1956 - A.A. Burlington Community College 1959 - S.M. University of Chicago 1964 - Ph.D. University of Chicago
PREVIOUS POSITIONS:	1959 - 1962: Research Assistant, University of Chicago 1962 - 1963: NASA Fellow at University of Chicago 1964 - 1966: Research Fellow, California Institute of Technology 1967 Senior Research Fellow, California Institute of Technology 1967 - 1971: Assistant Professor of Physics, California Institute of Technology
PROFESSIONAL SOCIETY MEMBERSHIPS:	American Physical Society American Geophysical Union

<u>PUBLICATIONS</u>: (partial list)

"The Physical Significance and Application of L, B_0, and R_0 to Geomagnetically Trapped Particles," E. C. Stone, J. Geophys. Res., <u>68</u>, 4157 (1963)

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"Calculations Concerning the Evolution of a Spectral Feature During the Decay Phase of a Solar Flare Proton Event," J. E. Lupton and E. C. Stone, submitted for publication

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PRESENT POSITION:	AST Fields & Particles, Cosmic Radiations Branch, Cosmic Ray Section
RESEARCH AREA EXPERIENCE:	Cosmic Rays Co-investigator on the Goddard Cosmic Ray Experiments on OGO I, III, and V and IMP IV and V
EDUCATION:	1962 - B.S. MIT 1967 - Ph.D. University of Maryland
PREVIOUS POSITIONS:	1962 Research Assistant, MIT 1962 - 1963 Teaching Assistant, U. of Maryland 1963 - 1964 Research Assistant, Adler-Westrex
PROFESSIONAL SOCIETY MEMBERSHIPS:	American Physical Society American Geophysical Union

PUBLICATIONS

"A Study of Low Energy Cosmic Radiation from 1961-1965," Thesis.

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NAME:	Dr. James H. Trainor
DATE OF BIRTH:	August 22, 1935
PRESENT POSITION:	Head, Instrumentation Branch
RESEARCH AREA EXPERIENCE:	Electronics, trapped radiation, solar protons, cosmic radiation
RECENT EXPERIENCE:	Co-Investigator for Experiments on OGO-F, IMP H and J, Pioneer F and G and Principal Investegator for the Cosmic Ray and Solar X-Ray Experment on Helios A and B; Experiment Manager, OGO-F, Pioneer F and G and Helios A and B Experiments; Assoc. Proj. Scientist, OGO-E; Study Scientist for S^3, Advanced IMP (I, H, J), Galactic Jupiter Probe and Outer Planets Explorer and IMP Mother/Daughter Mission; GSFC RTOP Manager for Advanced Technological Development (General) including solid state detectors, radiation effects, flight signal and data processing systems, tape recorders, balloon ACS system, etc; member GSFC Preferred Parts Steering Committee; NASA Liaison Representative to the Instrumentation Panel, Physics Survey Committee.
EDUCATION:	1958 - B.S. - Physics, University of New Hampshire 1959 - M.S. - Physics, University of New Hampshire 1964 - PhD. - Physics, University of New Hampshire
PREVIOUS POSITIONS:	9/56 - 9/58 - Tech. and Res. Assistant University of New Hampshire 9/58 - 6/59 - Grad. Assist., University of New Hampshire 6/59 - 9/62 - Instructor, Phycics 6/63 - 9/63 - Res. Physicist, University of New Hampshire 9/63 - 8/64 - Res. Fellow., University of New Hampshire
PROFESSIONAL SOCIETY MEMBERSHIPS:	American Geophysical Union (Solar-Planetary Relationships) IEEE (Prof. Group on Nuclear Science) Sigma Xi

PUBLICATIONS:

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NAME:	Dr. Rochus E. Vogt
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PRESENT POSITION:	Professor of Physics, California Institute of Technology
RESEARCH AREA EXPERIENCE:	Research on the astrophysical aspects of cosmic radiation. Principal investigator on NASA Grant NGR 05-002-160 supporting space research at Caltech. Co-investigator on cosmic ray experiments on NASA's OGO-6, IMP H & J, HEAO A
EDUCATION:	1957 - S.M. University of Chicago 1961 - Ph.D. University of Chicago
PREVIOUS POSITIONS:	1953 - 1961: Research Assistant, Enrico Fermi Institute for Nuclear Studies, University of Chicago 1961 - 1962: Research Associate, Enrico Fermi Institute for Nuclear Studies, University of Chicago 1962 - 1965: Assistant Professor of Physics, California Institute of Technology 1965 - 1970: Associate Professor of Physics, California Institute of Technology
PROFESSIONAL SOCIETY MEMBERSHIPS:	American Physical Society American Geophysical Union American Association of Physics Teachers American Association for the Advancement of Science

PUBLICATIONS: (partial list)

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"Interplanetary Deceleration of Solar Cosmic Rays," with S. S. Murray and E. C. Stone, Phys. Rev. Letters, 26, 663 (1971).

NAME:	Dr. William R. Webber	
EDUCATION:	COE College B. S., 1951	
	University of Iowa M. S., 1954	
	University of Iowa Ph.D., 1957	
PROFESSIONAL EXPERIENCE:	1957 - 1959	Imperial College, Research Fellow
	1959 - 1960	University of Maryland, Assistant Professor
	1960 - 1961	Imperial College, NSF Post-Doctoral Fellow
	1961 - 1964	University of Minnesota, Assistant Professor
	1964 - 1967	University of Minnesota, Associate Professor
	1967 - 1968	University of Adelaide, Visiting Professor
	1968 - 1969	University of Minnesota, Associate Professor
	1969 - present	University of New Hampshire, Professor

Partial List of
<u>PUBLICATIONS</u>

1. Determination of the Intensities of Low-Z Components of the Primary Cosmic R diation at $\lambda = 41^{o}$ Using a Cerenkov Detector, Phys. Rev. <u>100</u>, 1460, W. R. Webber and F. B. McDonald (1955).

2. New Determination of the Intensities of Primary Cosmic Ray a-Particles and Li, Be, B Nuclei at $\lambda = 41.5^{o}$ Using a Cerenkov Detector, Nuovo Cimento <u>4</u>, 1285, W. R. Webber (1956).

3. The Charge Composition and Energy Spectra of Primary Cosmic R ys and the Energy Balance Problem, Nuovo Cimento <u>8</u>, Supp. II, 532, W. R. Webber (1958).

4. Cosmic Ray Cut-off Rigidities and the Earth's Magnetic Field, Phil. Mag. <u>4</u>, 90, J. J. Quenby and W. R. Webber (1959).

5. The Variations of the Cosmic Ray Intensity during a Solar Cycle, <u>Proc. of First International Space Science Symposium</u>, Nice, pp. 968-81, F. B. McDonald and W. R. Webber (1960).

6. The Time Variations of the Low Rigidity Cosmic Radiation during the period 1954-60, review article in <u>Progress in Cosmic Ray Physics VI</u>, W. R. Webber (North Holland Pub. Co., Amsterdam, 1962).

7. Cerenkov-scintillation Counter Measurements of the Light, Medium, and Heavy Nuclei in the Primary Cosmic Radiation from Sun Spot Maximum, Jour. Geophys. Res. <u>67</u>, 2119, F. B. McDonald and W. R. Webber (1962).

8. The Motion of Low-rigidity Cosmic Rays in the Earth's Magnetic Field and the Effects of External Fields, Jour. Geophys. Res. <u>68</u>, 3065-85, W. R. Webber (1963).

9. Cerenkov-Scintillation Counter Measurements of the Intensity and Modulation of Low Rigidty Cosmic Rays and Features of the Geomagnetic Cut-off Rigidity, Jour. Geophys. Res. <u>69</u>, 3097-3113, W. R. Webber and F. B. McDonald (1964).

10. The Low Energy End of the Primary Proton, Alpha Particle and Heavier Nuclei Spectra, <u>Symposium on the International Year of the Quiet Sun</u>, Buenos Aires, August, 1964, W. R. Webber.

11. The Spectrum and Charge Compostion of the Primary Cosmic Radiation, <u>Handbuch d. Physik 46-2</u>, 173, W. R. Webber (Springer-Verlag-Heidelberg, 1967).

12. Measurements of the Abundance of Iron and Heavier Nuclei in the Cosmic Radiation, Astrophys. J. <u>147</u>, No. 3, 1205, J. F. Ormes, T. T. von Rosenvinge and W. R. Webber (1967).

13. Cerenkov-scintillation Counter Measurements of Nuclei Heavier than Helium in the Primary Cosmic Radiation - Part I, Charge Composition and Energy Spectra between 200 MeV/nuclon and 5 BeV/nucleon, J. Geophys. Res. <u>72</u>, 5957, W. R. Webber and J. F. Ormes (1967).

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15. A Large Area, High Resolution Scintillation Counter Telescope for Cosmic Ray Studies, <u>Nuc. Inst. and Methods</u>, T. T. von Rosenvinge and W. R. Webber (to be published).

16. The Relative Energy Spectra of Carbon and Oxygen Nuclei in the Primary Cosmic Radiation, Astrophys. and Space Sci. 3, 4, T. T. von Rosenvinge, W. R. Webber and J. F. Ormes (1969).

17. Measurements of Cosmic Ray Li, Be, andB Nuclei in the Energy Range 100 MeV/nuc to > 22 BeV/nuc, Astrophys. and Space Sci. 3, 80, T. T. von Rosenvinge, J. F. Ormes and W. R. Webber (1969).

18. Observations of Fluorine Nuclei in the Primary Cosmic Radiation made on the Pioneer 8 Spacecraft, Astrophysical J. 156, L73, J. Lezniak and W. R. Webber (1969).

19. Observations on the Abundance of Nitrogen in the Primary Cosmic Radiation, Astrophys. and Space Sci., J. A. Lezniak, J. F. Ormes, T. T. von Rosenvinge and W. R. Webber (in press).

20. A Comparison of the Energy Spectra of Cosmic Ray Helium and Heavy Nuclei, Astrophys. and Space Sci., T. T. von Rosenvinge, W. R. Webber and J. F. Ormes, (in press).

APPENDIX H

INSTRUMENT FACT SHEETS

PROPOSER'S NAME Vogt et al

SHORT TITLE OF PROPOSAL Interstellar Cosmic Ray and Planetary Magnetospheres Experiment

PROPOSAL NUMBER (FOR NASA USE) ______

PARAMETER	INFORMATION
A. Instrument Location	
1. Sensor	Scan Platform ______
	Cruise Platform X
	Bus: Internal ______
	External ______
	Boom ______
	Other (Specify) ______
2. Electronics	Scan Platform ______
	Cruise Platform X
	Bus: Internal ______
	External ______
B. Weight and Size	
1. Remote* From S/C Electronics Compartment (Bus)	4.45 KG.
	30 X 30 X 35 CM.
2. Bus	0 KG.
	___ X ___ X ___ CM

*If more than one remote package please provide requested information for each package.

C. Power (S/C Power is 2.4 kHz, 50V RMS Squarewave, +3% -4% Regulation)

1. Remote* from S/C Electronics Compartment (Bus) — Steady State 4.8 WATTS

2. Bus — Steady State 0 WATTS

3. Estimate of Maximum Power Required at Turn On and Mode Change and Length of Transient.
   Turn On ____% of Steady State for ____MS
   Mode Change ___% of Steady State for ____MS
   not accurately known yet

4. Special Energy Storage Requirement
   Describe Power to heat and drive piston for rotation mechanism. Example: 5 watts for ~10 minutes for 180° rotation.

D. Thermal Requirements*

			Preferred Temp.	
1. Operating Temp. Range				
a. Proper Operation	-40°C TO +35	°C	0 °C	center
b. Out of Calibration (No Damage)	-50°C TO +35	°C		
2. Non-Operating Temp. Range	-60°C TO +35	°C	20 °C	
3. Maximum and Minimum Temp. With No Damage to Instrument.	35 °C MAX. -60 °C MIN.			

*If more than one remote package, provide requested information for each package.